

Chapter 5 -- **BENEFITS FROM MONITORING AND RESEARCH PROJECTS**

The State of Wisconsin has funded over 330 groundwater-related monitoring and research projects since enactment of Wisconsin's comprehensive groundwater protection legislation (1983 Wisconsin Act 410) in 1984 (see *Appendix C*). Those agencies that have funded projects are the DNR, DATCP, DILHR/Commerce, and the UW System.

This chapter highlights some of the areas that have been the focus of research and monitoring projects and illustrates how agencies have used the project results to improve the management of the state's groundwater resources. Many projects have contributed to our understanding of subsurface hydrology, surface water and groundwater interactions, and geology. Some have helped to evaluate existing regulatory programs and determine if there is a need for additional regulations. Numerous studies have increased the knowledge of the movement of contaminants in the subsurface. Others have developed new methods for groundwater evaluation and protection.

Citations refer to the projects listed in the table in *Appendix C*.

PHARMACEUTICALS AND PERSONAL CARE PRODUCTS IN GROUNDWATER

Pharmaceuticals and personal care products (PCPs) are a large group of substances present in human generated waste streams that potentially could contaminate groundwater resources. Pharmaceuticals such as antibiotics, birth control pills and various prescription medicines may be present in wastewater effluents. PCPs, including shampoos, detergents and "over the counter" medications, are found in both treated wastewater discharges and the municipal solid waste stream. Some pharmaceutical/PCP compounds may act as endocrine disruptors, adversely affecting the behavior of natural hormones in humans and other animals. New analytical methods, allowing detection of very small quantities of a substance, have helped improve investigations into the occurrence of pharmaceuticals and PCPs in the environment.

Discharges of treated wastewater through land treatment systems, leachate leaking from solid waste landfills, and agricultural/municipal biosolids landspreading activities can potentially contaminate groundwater aquifers. The mobility and fate of discharged/released substances in the subsurface is a function of a variety of factors such as adsorption properties and biodegradability of the substance, and the amount and properties of the soil material through which the substance is passing. Recent studies in other states, assessing the occurrence of pharmaceuticals and PCPs, have shown the presence of these substances in groundwater at sites where treated wastewater is used to recharge groundwater.

In Wisconsin, research has been done evaluating the occurrence, and movement in the subsurface, of pharmaceuticals and PCPs. A 2003 University of Wisconsin (UW) study, conducted by K.G. Karthikeyan and William F. Bleam, investigated the presence of antibiotics in treated wastewater effluents, and their potential fate in the subsurface. Two antibiotics, tetracycline and sulfamethoxazole, were found in all of the wastewater effluents tested for the study. A variety of other antibiotics were also detected in the tested wastewaters. Tetracycline and sulfamethoxazole were found to be present in groundwater monitoring wells located directly adjacent to some of the

study land treatment system discharge areas.

A second UW study, conducted by Joel Pedersen and K.G. Karthikeyan, has investigated the soil adsorption properties of common antibiotics. This study found that under the right soil conditions some antibiotics, such as the sulfonamide antibiotics, have the potential to be fairly mobile in the subsurface.

Several other pharmaceuticals/PCP studies are currently in progress. A study of the use of a screening assay to evaluate the occurrence of estrogenic endocrine disruptors in groundwater is currently being conducted by the WSLH. This study is to include testing of both high capacity water supply wells located in close proximity to surface waters (where wastewater effluent is being discharged), and water supply wells in the vicinity of home on-site wastewater treatment system discharges to groundwater. A Dane County research project, assessing groundwater impacts from on-site wastewater treatment system discharge, is also currently underway. This project will include an assessment of pharmaceuticals and PCPs in both soil water and groundwater impacted by on-site system discharges in an unsewered subdivision.

The Department has begun to use the results of these recent pharmaceutical and PCP research studies to evaluate whether current state groundwater protection regulations are adequate to address potential adverse impacts that might result from the discharge of these substances. Studies comparing the levels of pharmaceutical and PCP substances in wastewater influent with those present in treatment system effluents will be useful in assessing the removal effectiveness of currently approved wastewater treatment processes. Research into the behavior of pharmaceutical and PCP substances in soil and groundwater is helping the Department develop effective monitoring strategies. Studies evaluating new sampling techniques and analytical methods help assure that the Department is utilizing the best available tools to assess the occurrence of these substances in the environment.

THE ATRAZINE RULE

The development of the Atrazine Rule (ATCP 30, Wis. Adm. Code) illustrates how the benefits of state-funded research and monitoring can build on one another. In the mid-1980s the corn herbicide atrazine was first detected in monitoring wells and private drinking water wells in Wisconsin. The first systematic well sampling program to characterize atrazine contamination on a statewide basis was the 1988 DATCP Grade A Dairy Farm Well Water Quality Survey (LeMasters, 1989). This state-funded well survey estimated that atrazine was present in 12% of the Grade A Dairy Farm Wells in the State.

This study left unanswered many questions regarding the sources, groundwater susceptibility, and the presence of pesticides other than atrazine. Without better information on these and other questions, it was challenging for DATCP, the agency charged with groundwater protection related to agricultural chemicals, to develop a plan of action. It was obvious that a concerted information gathering program was needed. Over the next several years, before and during the development of the DATCP atrazine rule, the Wisconsin Groundwater and Pesticide Research Program played an essential role in providing the needed information. Research and monitoring were conducted on several topics that played a direct role in the evolution of the atrazine rule.

The state research and monitoring program funded several key projects to better understand the sources of atrazine contamination. When atrazine was first found in groundwater, an argument had been made that this was the result of point sources such as spills and mishandling. One of the most important findings that allowed DATCP to begin developing the atrazine rule was that

normal agricultural applications of atrazine could lead to groundwater contamination. The DATCP groundwater monitoring project for pesticides (Postle, 1986-96) used monitoring wells located next to agricultural fields to study groundwater contamination by atrazine and other pesticides. This study showed that atrazine from field use on sandy soils could cause contamination, often above the 3 µg/L ES. The UW Water Resources Center conducted a detailed hydrogeologic study (Chesters, 1990-91) at a farm in Dane County and showed conclusively that atrazine contamination could result from both field applications and mixing/loading practices. With the knowledge that nonpoint contamination of groundwater by atrazine was indeed occurring, DATCP could develop ways to reduce this contamination.

State-funded research was essential in showing that atrazine contamination did not follow simplistic notions of groundwater contamination susceptibility. One of the most important findings was that the Central Sands and the Lower Wisconsin River Valley (LWRV), two areas that appear similar in soils and agricultural practices, had significantly different susceptibility to contamination. These differences were pointed out in several research projects conducted by the UW Soil Science Department (Daniel, 1991; Lowery, 1991; McSweeney, 1991; Lowery, 1992-3). This information had a direct influence on the atrazine rule in that there is now a use prohibition in the LWRV and managed use in the Central Sands.

Another key finding related to the susceptibility of groundwater to atrazine contamination was that many of the areas with high frequency of detections had medium textured (loamy) soils. It had previously been thought that these areas were less susceptible to leaching and groundwater contamination than areas with sandy soils. State-funded research and monitoring efforts, however, showed that the intensity of atrazine use, in addition to soil and geologic conditions, played an important role in the contamination. This finding helped to explain why many areas in south central Wisconsin, with medium textured soil and high corn production, had many wells contaminated with atrazine. This knowledge allowed DATCP to adopt management strategies for reducing atrazine contamination in these areas.

When atrazine was first discovered in Wisconsin's groundwater in the mid-1980s, DATCP was interested in managing its use based on predictive modeling of contamination processes. Modeling activities funded by the state research program, however, indicated that the behavior of atrazine and other contaminants in the environment was complex and could not be reliably predicted by modeling. In response to this finding, DATCP adopted a more empirical approach to identifying management areas. Actual well results were plotted on maps and, together with an analysis of soils and geology, management areas were delineated.

When monitoring and rule making efforts for atrazine first started, parent atrazine was the only compound that was considered. As more research was conducted, however, it was discovered that three metabolites (breakdown products) of atrazine were present in groundwater and were of health concern (Chesters, 1990-91; LeMasters, 1990; Cowell, 1990; Cates, 1991). State-funded sampling programs showed that due to the presence of atrazine metabolites, the groundwater problems were more serious than previously considered. This knowledge allowed DNR to strengthen the groundwater standard for atrazine in 1992 and allowed DATCP to strengthen the atrazine rule in 1993 and extend required use reductions to the entire state.

It is interesting to try to envision how DATCP's atrazine rule would look if it did not have the benefit of the intensive research and monitoring efforts. It is safe to say that it would not have been developed on as good an understanding of the behavior of atrazine in the environment or the geographic patterns of contamination. It is possible that without the intensive monitoring efforts, the full extent of the problem would not have been discovered and atrazine use would not have

been reduced. On the other hand, it is possible that with inadequate knowledge a "broad brush" approach would have been taken. This could have resulted in unfair regulations that were not tailored to the different geographic areas of the state.

Two important aspects of environmental regulation that promote its acceptance are that it is based on science and that it is fair. Good research is necessary to achieve these two characteristics. The Atrazine Rule has experienced a relatively high degree of acceptance due to the effort that was put into its development.

GROUNDWATER MONITORING AT SOLID WASTE DISPOSAL SITES

The DNR's Waste and Materials Management (WMM) program received project funding ten times from 1985 to 2003 through the joint solicitation process. These projects have benefited the program in many ways, primarily impacting regulations and monitoring practices.

The first two studies (Friedman, 1985-87; Battista, 1988-89) revealed for the first time that groundwater around many Wisconsin landfills was contaminated by VOCs. The studies also showed that VOC contamination of groundwater was more common at unlined municipal solid waste landfills than at other types of landfills. A follow-up VOC study (Connelly 1993-94) showed that VOC levels have decreased at most of the unlined landfills, though at many of the sites VOC levels do not show continued decline. There was no VOC contamination definitely attributable to leachate migration at any of the older, engineered landfills that confirmed that these sites are performing as WMM program staff had hoped. The results of the three VOC studies have been used to establish requirements for VOC sampling at new and existing landfills. These studies have also indicated that inorganic compounds could be useful in predicting VOC contamination at landfills. Therefore, until recent EPA rules required VOC monitoring, the WMM program allowed sites to sample for inorganic parameters as part of routine monitoring and not sample VOCs until inorganics were elevated. The VOC studies provided valuable data that was used to convince EPA to reduce the number of VOCs required for monitoring at municipal solid waste landfills in Wisconsin. This reduction in monitoring (the use of inorganics and the reduced number of VOCs when they are required) allowed landfill owners considerable cost savings while maintaining equivalent environmental protection. Additionally, the VOC data was used to require responsible parties to define the degree and extent of contamination and remediate groundwater contamination at their landfills.

Research on methods of assessing groundwater quality data and data quality control completed in the third VOC study has been helpful to WMM program staff and consultants in interpreting groundwater quality data from landfills and other facilities. This study also showed the need to require laboratories to report data between the limit of detection and the limit of quantitation.

An assessment of Wisconsin's Groundwater Monitoring Plan program (Pugh, 1992) for active non-approved landfills provided the documentation of a set procedure for selecting monitoring sites. This information has been useful in recent meetings with municipalities held to convince municipalities that they have not been singled out for further evaluation of groundwater contamination and to demonstrate that the process used for selecting landfills for monitoring is objective.

Three studies from 1991 to 1994 on the potential groundwater impacts at deer pits, yard waste sites, and construction and demolition landfills (Pugh, 1992-3; Pugh, 1994) were conducted because little or no data existed on the potential impact to groundwater from these sites. Research has provided the information necessary to revise rules and establish policy regarding monitoring

and siting of construction and demolition (C/D) landfills, deer pits, and yard waste sites in Wisconsin. The groundwater study of deer pits showed that impacts were minimal and helped the WMM program to decide not to require liners and to loosen some construction and reporting requirements. Similarly, the yard waste site study showed only minor groundwater impacts, which led the WMM program to encourage active management of these sites rather than stiffen regulations. The study of construction and demolition landfills showed some groundwater impacts at large sites but little or no impacts at smaller sites. These findings led to new regulations (effective June 1996) allowing lined intermediate size C/D landfills, which can provide the economic benefits of a large site without the potential negative impacts of very large sites. Based on the research, the regulations were written to require groundwater monitoring of inorganic parameters at small size C/D landfills but only require VOC sampling when establishing background. Since these studies have been conducted, many states and the EPA have contacted the WMM program about the information collected.

Another study undertaken by the WMM program (Connelly, 1994) was a comparison of groundwater sampling methods for collecting metals samples at monitoring wells. The study was in response to EPA's October 1991 ban on field filtering of groundwater samples that became effective in October 1994. The WMM program opposed this ban because many Wisconsin monitoring wells produce very turbid water which can lead to false positive results for metals if samples are not filtered. Additionally, the new EPA-recommended procedure, low-flow pumping, requires a significant amount of additional equipment. The study showed that the low-flow pumping method was appropriate in many circumstances but could not be used to sample slowly recovering wells. The results showed that turbidity was the best indicator that a well has been sufficiently purged. The results of the investigation are being used to revise groundwater sampling procedures required by the WMM program. Additionally, the study helped establish Wisconsin as one of two leading states playing a major role in advising EPA on revisions to their groundwater sampling requirements at municipal solid waste landfills.

A follow up study by the WMM program (Svavarsson, 1995) compared low flow pumping and bailing for VOC groundwater sampling at landfills. The study indicated that, in contrast to what some were claiming, there was very little difference in the results when using the two different methods. These findings were incorporated into the new groundwater sampling code and allowed the use of either method for sampling VOCs. This reduced the cost that landfill owners would otherwise have had to bear to purchase and operate low flow pumping equipment.

A joint project between the Bureau and UW Stevens Point evaluated the effectiveness of chemical oxygen demand (COD) as an indicator parameter at landfills (Connelly and Stephens, 2000). One reason for evaluating COD is that mercury waste is generated when COD is analyzed in the laboratory. The DNR's overall goal was to reduce amount of mercury that gets into the environment. Eliminating COD sampling at the 400+ landfills that currently sample for it would help the agency meet that goal. Findings from the first year of the study indicated that there are potential to eliminate COD monitoring at some types of landfills. The second year of the study evaluated possible alternatives to sampling for COD. Dissolved organic carbon (DOC) appears to be an acceptable alternative in certain circumstances. WMM staff have incorporated the recommendations of this study into code changes that went into effect in February 2006.

Between July 2000 and July 2001 the Bureau studied 31 landfills accepting municipal solid waste, to try to determine whether VOC contamination in groundwater at these landfills is increasing, decreasing or remaining stable (Connelly 2001). Investigators chose sites with 10 years of data and summarized the trends over this period of time. One purpose of this study was to determine whether natural attenuation is occurring in groundwater near leaking landfills. The

study showed that natural attenuation processes were occurring at most of the landfills as evidenced by the large number of stable or decreasing concentration trends. However, the concentrations took longer to stabilize and stabilized at higher levels than at other types of VOC contamination sites described in the literature.

WMM received funding for the period October 2002 to October 2003 to study groundwater quality at solid waste landfills to determine whether they are a source of pesticide contamination. We sampled 11 sites the spring and summer of 2003 and summarized the findings in a 2005 GEMS Newsletter article. Groundwater samples were analyzed for 14 common Wisconsin pesticides using immunoassays and additional GC/MS methods. Preliminary findings indicated that leaking landfills may be contributing alachlor, aldicarb, atrazine and 2,4-D to groundwater. The study researchers believed a follow-up study was needed to provide more evidence to help make concrete recommendations about which pesticides to sample for. However, staff and funding are not currently available for this.

ARSENIC MONITORING AND RESEARCH IN NORTHEASTERN WISCONSIN

Wisconsin is also a leader in groundwater monitoring for naturally occurring compounds. Two projects in the DNR Lake Michigan District (Stoll, 1992; 1994) identified the existence of lead and arsenic contamination in groundwater. Homeowners were alerted through direct mailings, public meetings and mass media news releases. Over 72,000 people were unaware of their exposure to the substances in their drinking water. In one case, the sources of metals in these drinking water supplies were given priority for removal (Door County Lead Arsenate Mixing Sites).

The DNR coordinated with the DHFS to conduct health surveys on individuals consuming locally contaminated water supplies and made appropriate health recommendations. Local County Health Departments in affected areas are also actively monitoring groundwater quality and are providing assistance to homeowners. In 2001 and 2002, DHFS staff received additional funding to conduct a follow-up investigation on the relationship between exposure to inorganic arsenic in water and health outcomes (Knobeloch 2001). As part of this research effort, local health departments, DNR staff, town clerks and others have conducted well sampling campaigns in townships in the affected counties.

2233 households submitted samples and returned health surveys, providing health and exposure information for 6669 individuals. Approximately 20% of the water supplies contained arsenic levels above 10 µg/L. Slightly more than 10% of the families consumed water that had an arsenic level greater than 20 µg/L. People over the age of 50 were more likely to report a diagnosis of skin cancer if they had consumed water that had an arsenic concentration greater than 5 µg/L for 10 years or more. Cigarette use was also associated with higher skin cancer rates: residents who both smoked and consumed arsenic-contaminated water reported the highest skin cancer prevalence rate. No association was seen between exposure to arsenic-contaminated water and the incidence of other types of cancer. However, findings from this study were consistent with previously reported associations between arsenic exposure and the prevalence of adult onset diabetes and cardiovascular disease.

As part of this study, DHFS conducted a survey of households in selected areas of northeastern Wisconsin affected by arsenic in groundwater. The goal of this survey was to assess residents' understanding of their laboratory results, learn what actions people have taken in response to their results, and to identify barriers to increased participation in well sampling campaigns. The survey revealed that more than 80% of those who perceived their well water to be unsafe had taken

action to reduce their exposure to arsenic, usually by installing a treatment system or by drinking bottled water. Among those who had not sampled their wells for arsenic, confidence in the safety of their well and lack of information about how to have their water tested were the most commonly cited reasons. Many of those who had not had their wells tested had reported that they had only recently moved into their homes or into the area.

Studies conducted by DNR of the extent of the arsenic contaminated area led to the establishment of an “Arsenic Advisory Area” (AAA) in the early 1990s. This area includes the strip of land five miles either side of the bedrock subcrop of the St. Peter Sandstone, extending in a northeasterly trend, from a location just southwest of Oshkosh, to a location just west of Green Bay. For this area, DNR developed special well construction specifications, more stringent than the minimum Private Well Code requirements. DNR guidance recommends the installation of 80 feet of casing through the sandstone contact for drinking water wells in the AAA. These specifications were recommended, but not required, for new wells constructed within the “Arsenic Advisory Area”. The specifications, when followed, will increase the likelihood of installing a well free of arsenic. A special well casing depth area (SWCDA) has been established for the Town of Algoma in Winnebago County. In this area, all wells must be drilled with mud/wash rotary methods with a 10-inch upper enlarged drillhole, Bradenhead grout methods and cased to the Cambrian sandstone aquifer.

In 2002 the WGNHS completed field experiments in the Fox River Valley that evaluated mechanisms of arsenic release to groundwater from domestic wells completed in the St. Peter sandstone aquifer, including studies of arsenic exposure to residents in the area and the effects of well chlorination on arsenic levels (Gotkowitz 2001). Findings support the hypothesis that high levels of arsenic in groundwater occur where mineralization is oxidized in well boreholes. However, two distinct geochemical mechanisms appear to contribute low to moderate arsenic concentrations to well water in this aquifer. 1) Oxidation of sulfide minerals may release arsenic to groundwater in confined portions of the aquifer; oxidation may have occurred at some time in the geologic past, or current levels of oxygen dissolved in the groundwater may be sufficient to permit slow oxidation to occur. 2) Reductive dissolution of arsenic-bearing iron oxides also seems to contribute low to moderate levels of arsenic to groundwater when the geochemical environment becomes sufficiently reducing. This occurs under typical domestic water use patterns, because increasing groundwater residence time in wells correlates to the onset of strongly reducing conditions and higher arsenic concentrations. The well borehole is a microbiologically active environment, and biogeochemical reactions likely contribute to the observed increase in arsenic concentrations. Reducing the volume of well bore storage relative to water use may help to limit arsenic concentrations in well water. Results of this study were presented to DNR Drinking Water and Groundwater Program staff and used by the DNR to develop well construction guidelines for the Towns of Algoma and Omro.

Several other ongoing projects addressing arsenic issues include a study refining analytical methods for detection of arsenic compounds (Aldstadt 2001), a study of the role of chlorination in releasing arsenic (Sonzogni 2002), three projects investigating treatment methodologies for both private and public water supplies (Anderson 2001, Park 2002, McGinley 2002), and a project investigating the occurrence of arsenic in southeastern Wisconsin aquifers (Bahr and Gotkowitz 2003). These studies will help provide needed information about the occurrence, health risks, and remediation of arsenic in drinking water supplies. Results will be made available as final reports are completed.

GROUNDWATER MOVEMENT IN FRACTURED DOLOMITE

Door County has been the site of five research projects by the WGNHS to develop a framework for studying the complex groundwater flow regime in fractured rock found in many parts of the state. The first project (Bradbury, 1986-90) started as a nonpoint source watershed project investigating the hydrogeology and groundwater geochemistry in the shallow fractured dolomite aquifer in Door County. Groundwater quality was found to vary widely over time with bacteriological contamination common. The second study (Bradbury, 1992) showed that modeling results obtained from a discrete fracture model varied considerably from results produced by a continuum model for groundwater movement. The discrete fracture model estimated capture zones, groundwater flow paths, and groundwater travel times by using mathematical representations of fractures digitized from aerial photos. The third study (Bradbury, 1993-94) used a tracer for characterization of groundwater movement and contaminant transport. It revealed that hydraulic conductivity can vary widely in the same well depending on what depth interval is tested.

A fourth study applied the discrete fracture flow model above to wellhead protection at the City of Sturgeon Bay (Bradbury 1996). Municipal wells at Sturgeon Bay draw groundwater from a series of horizontal fracture planes in Door County's dolomite aquifer, and delineating wellhead protection areas in such environments is extremely challenging. This complex project has relied upon hydrogeologic information and analytical tools developed through the three research projects described above which targeted processes and models for groundwater movement in fractured rocks. Without the knowledge and experience gained through these previous projects the Sturgeon Bay Wellhead Protection Project could not have been accomplished.

During 1999, Bradbury and others began a follow-up project to attempt to verify the results of the Sturgeon Bay wellhead protection project using natural groundwater tracers (Bradbury 2000). This research measured the natural seasonal variations in temperature, electrical conductivity, and oxygen and hydrogen isotopes of groundwater and precipitation in order to verify the sources and velocities of groundwater moving toward Sturgeon Bay's wells. The use of such tracers is attractive because they are naturally present in the environment. The geochemical and isotopic data are consistent with conceptual and numerical groundwater models near Sturgeon Bay. Both the field study and the numerical model show that the dolomite aquifer responds very rapidly to precipitation events. Advective transport simulations using particle tracking produce concentration breakthrough curves consistent with field results.

DEVELOPING NEW TOOLS FOR GROUNDWATER PROTECTION

Applications of a wide variety of tools for gathering and working with hydrogeologic and groundwater quality data have been funded. Projects involving Geographic Information Systems (GIS) and sophisticated groundwater modeling applications have been funded in the many areas of the state. The funding agencies hope to continue to develop improved methodologies to make groundwater quality, quantity and contaminant source data more readily available.

Previous support of county-wide groundwater inventory studies and of modeling methodologies (Potter, 1992-93; Anderson, 1997) has given WGNHS and USGS personnel the hydrogeologic databases and analytical tools needed for the construction of regional groundwater models such as the recently completed Dane County groundwater model. This computer model, which covers all of Dane County, simulates current and future groundwater conditions and is being used to evaluate how current and future groundwater pumping affects regional water levels and also how

groundwater use affects shallow lakes, streams, and wetlands. In addition, this model has been used to delineate groundwater capture zones for all municipal wells in Dane County (Bradbury 1996).

The Dane County model, which provides a modern hydrogeologic framework for groundwater movement in Dane County, has stimulated a number of significant research projects by other investigators (Mickelson 1994-95; Bradbury et al., 2000). These investigators are using the model as a starting point for more detailed flow models of specific problems or areas of the county. One of the most significant of these is the award of a multi-year USEPA STAR grant to a team of DNR, UW-Madison, USGS, and WGNHS investigators who are investigating the water-resources impact of different land-use strategies on Madison's urban fringe. This research will support several graduate students and will provide an integrated assessment of the hydrological, ecological, and institutional impacts of urbanization and land-use change. This research is focused on the Pheasant Branch watershed just west of Madison. Other research projects are investigating the sources of groundwater supplying important springs in the Nine Springs and Token Creek watersheds, with the goal of determining how nearby development and groundwater use could affect the springs.

The Dane County model has now become a prototype for regional groundwater models in other parts of Wisconsin. In 2003, the WGNHS, USGS, and SEWRPC finalized a cooperative project to develop a similar model for the entire seven-county SEWRPC area of southeast Wisconsin. Other modeling projects are taking place in Sauk, Rock, and La Crosse Counties. Such models are critical tools in the planning process, and allow water managers to evaluate the impacts of various future water management and land use alternatives in order to make well-informed land-use decisions.

PREVENTION AND REMEDIATION OF GROUNDWATER CONTAMINATION

The State of Wisconsin (through the UWS Water Resources Institute) has supported many research projects emphasizing new technologies for prevention or remediation of groundwater contamination. Final reports and studies in progress provide information or products that will be important for future efforts aimed at controlling or attenuating groundwater contamination in Wisconsin. The findings cover a wide range of technologies including:

- New and enhanced physicochemical or biological methods to renovate waters contaminated by pesticides and volatile organic carbon compounds (Collins, 1997-2002), (Li, 2000), (Benson and Eykholt, 2000), (Benson, 1997-2000), (Hoopes, 1997-99), (Park, 1997-98), (Bahr, 1996-98), (Hickey, 1994-96), (Anderson, 1994-95), (Chesters and Harkin, 1991), (Harris and Hickey, 1991-92);
- Enhancements in the ability to control, monitor, and predict the movement of landfill and mine waste contaminants to groundwater (Edil and Benson, 2000), (Edil 1997), (Benson, 1995-96), (Edil and Park, 1992-93);
- Improvements in the predictability of pump-and-treat remediation applications to contaminated aquifers (Bahr, 1994-95);
- Innovative agricultural practices designed to reduce groundwater contamination by pesticides and nitrate (DeVita and Dawson, 2001-04), (Norman, 2000-03), (Bundy, 1993-94, 1997-98), (Shinners, 1995-96), (Newenhouse, 1995), (Harrison, 1992-93), (Bahr, 1991-92); and
- Development of new technologies for evaluating the integrity of water supply well and exploration borehole seals (Edil, 1996, 1998-99), (Edil and Benson, 1997-98).

DETECTION AND MONITORING OF MICROBIOLOGICAL CONTAMINANTS

The GCC has solicited research projects during the last several years that attempt to improve understanding of microbiological aspects of groundwater contamination.

Several projects have focused on developing new techniques for detecting, quantifying, and monitoring microorganisms in groundwater and soils. Researchers at the UW-Madison Soil Science Department, developed a rapid molecular method using the polymerase chain reaction (PCR) to assay soils for the presence of specific sewage-borne pathogens (Hickey 1997). PCR-based methods eliminate the need to culture organisms for detection, and remedy shortcomings of traditional techniques by allowing rapid, sensitive, and specific identification of the pathogens of concern rather than indicator organisms. The PCR protocol Hickey developed was designed to detect DNA originating from *Escherichia coli*, which is one of the major species of bacteria associated with human waste. With this method he could distinguish *E. coli* DNA from that of its closest relative, *Shigella*. The method allowed the detection of DNA equivalent to about 20 cells. Currently, he is testing the PCR method for tracking of *E. coli* in the environment.

Because they have the capacity to co-metabolize a wide variety of organic chemicals, including halogenated compounds, methanotrophic bacteria have significant potential for bioremediation. The UW-Milwaukee Department of Biological Sciences has developed methods for quantification of methanotrophs in groundwater (Collins 1997, 1999). These methods, that include competitive PCR and direct PCR, provide approaches to monitoring bioremediation and natural attenuation. In addition, this work has provided the basis of another study that applied direct PCR to the detection of pathogens in groundwater (Collins 2001).

A recently completed study by the Wisconsin State Laboratory of Hygiene (WSLH) investigated storage and handling requirements for water samples submitted for coliform and *E. coli* analysis (Sonzogni and others, 2002). Currently the USEPA has no guidelines for sample holding times and shipping temperatures for drinking water samples submitted for *E. coli* testing. The study provided evidence to expand the allowable storage time of water samples submitted for *E. coli* analysis beyond the current eight hour limit as well as supporting a single preservation protocol for both surface waters and drinking water samples. A change to a maximum holding time of chilled samples for up to 30 hours could easily be supported by the data presented in this study. The data also called into question the current practice of allowing up to 48 hours for submitting drinking water samples with no attempt to cool them. A reduction in the time period to 30 hours, or a requirement to ship the samples at less than 10 degrees C, could be supported by the data.

Another recent WSLH study developed a culture method for detecting *Helicobacter pylori* from a heterogeneous microbial population in water, and then use this method to establish a data base for its occurrence in Wisconsin groundwater (Sonzogni and others 2002). Prior to this study, there were no reliable methods for detecting viable *H. pylori* in environmental samples (water, manure, vegetables, etc.). *H. pylori* is recognized by the World Health Organization to be the primary cause of peptic ulcers, chronic gastritis and stomach cancer. About 50% of the U.S. population are thought to be symptomatic or asymptomatic carriers, even though the source of human infection is not well understood. The efforts of this study resulted in the development of a high quality plating media for selecting viable *H. pylori* from mixed microbial populations. Samples from over 400 private wells were *H. pylori*-absent, including wells used by infected residents. These results suggest that the route of *H. pylori* to humans in Wisconsin probably does not involve private well water.

The Marshfield Clinic Research Foundation has investigated the association of pathogenic viruses and bacteria in private wells with incidences of infectious diarrhea and indicators of well water contamination (Borchardt 1997, 1999). In general, infectious diarrhea was not associated with drinking from private wells, nor was it associated with drinking from wells positive for total coliform. However, wells positive for enterococci were associated with children having diarrhea of unknown etiology, which was likely caused by Norwalk-like viruses. Final results indicate that the incidence of virus contamination in private wells may affect 4-12% of private wells. Of concern to drinking water regulators is the seasonal variability of the virus occurrences and lack of correspondence between viral presence and common microbial indicators.

In another recently completed study with the US Geological Survey, Marshfield researchers found that 50% of water samples collected from four La Crosse municipal wells were positive for enteric viruses, including enteroviruses, rotavirus, hepatitis A virus, and Norwalk-like virus (Hunt and Borchardt, 2002). As with the private well study, there was no correspondence to common indicators of sanitary quality. More surprising, there was no relationship between presence of surface water in the well water samples as determined by isotope analysis and virus occurrence. These findings suggest that viruses may be more common than expected in drinking water samples, although they do not indicate whether the viruses are viable, are inactivated through disinfection processes, or result in illness in the community. Research into the link between virus occurrence and human health is needed to answer these questions.

GROUNDWATER DRAWDOWNS

Large-scale withdrawals of groundwater are adversely affecting the environment, economy and public health in large areas of Wisconsin. These drawdowns can cause the water level in wells, streams and wetlands to drop or cause them to dry up entirely. Drawdowns can also cause the levels of arsenic, radium (the precursor to radon) and salinity in drinking water to increase.

State-supported research is using groundwater information and groundwater flow models developed at a regional scale and adapting it for use at the local level. In Washington County, researchers are working with the city of Richfield to develop a protocol for quantifying its groundwater budget (Cherkauer, 2003). That information will be coupled with projected changes in land use and pumping demand to define the effects of several development scenarios on the community's water supply. Once developed, this protocol will enable other communities to decide how to best protect vital groundwater recharge areas, local streams, lakes and wetlands.

Another project is investigating the sources of high salinity and radium in the deep sandstone aquifer that supplies water to residents of eastern Wisconsin (Grundl and Bradbury, 2003). This project is examining in detail the chemistry of the groundwater and the rock formations of this complex aquifer and determining whether high pumping rates are raising salinity and radium levels. This will help city planners and water utility directors better understand the relationship between well operations and water quality in this region, and evaluate effects of urban growth on water supplies.

Regional studies have identified central Waukesha County as an area where continued deep groundwater pumping might be causing the deep aquifers to become unconfined as water levels fall. A 2004 project installed one deep piezometer near Pewaukee for use as a monitoring point to document water-level declines. In 2006 the WGNHS will complete a study to help understand the vertical movement of groundwater through the regional Maquoketa aquitard, with emphasis on the possible effects of cross-connecting wells and fractures.

Other State-supported research is investigating the viability of aquifer storage and recovery (ASR) for Wisconsin, where excess water is stored in aquifers when demand is low and withdrawn for use when demand increases (Anderson, 2003). Computer models of groundwater flow and transport in ASR systems are being developed for two representative groundwater systems in Wisconsin. A better understanding of pumping rates, storage times and other factors that affect recovery efficiency of ASR systems will help guide future decision-making about using these systems in Wisconsin.

COMPREHENSIVE PLANNING

The State of Wisconsin has required Wisconsin towns, cities, villages and counties to develop comprehensive plans by 2010 in order to undertake common land use activities such as zoning and land division regulation. Communities that rely on ground water as their sole source of water need to assess the magnitude and limits of their water source as part of their comprehensive development plan, but most have little expertise in quantifying and protecting their water supply. A two-year project funded by the University of Wisconsin Water Resources Institute (WRI) partnered with such a community (Richfield, Wis.) to determine what kinds of groundwater supply information was most relevant and usable for land use planning from a community's perspective. This study determined that the most important information needed by such a community is a good basic understanding of the geology, sources, sinks and water balance of its aquifer system so that residents and community leaders know where their water comes from. Interaction with users at all levels is also crucial to developing the awareness needed to create a long-term land use plan and supporting laws to ensure a sustainable water supply under foreseeable future conditions. The next step is to share this model with other communities to help them plan how best to actively manage and protect the recharge areas that supply their water.

A related WRI project evaluated whether Wisconsin communities are addressing groundwater in their comprehensive plans, and what tools would make them more likely to do so. This project providing multiple presentations to local and state groups involved in groundwater planning; a webpage of study results; articles in a Center for Land Use Education newsletter distributed to more than 160 community planners and educators; a presentation to about 100 people at the 2005 conference of the American Water Resources Association-Wisconsin Section; and publication of an article in a national journal (Comprehensive Planning in Wisconsin: Are Communities Planning to Protect Their Groundwater Water Resources IMPACT 7(6):19-21).

MICROBIOLOGICAL GROUNDWATER MONITORING

Protecting groundwater from microbial contamination is a top public health priority. The United States and Canada experience significant levels of gastrointestinal disease from drinking water, more than 70 percent of which is associated with contaminated well water. A UW Water Resources Institute project examined the strengths and weaknesses of 10 enzyme-based tests approved by the U.S. Environmental Protection Agency for detecting total coliform and *E. coli* in drinking water. The results suggest these tests differ significantly in their ability to detect/enumerate total coliforms and *E. coli* and to suppress false positive results from *Aeromonas*, a non-coliform organism. The most significant of these findings was the inability of some test method/sample matrix combinations to even detect *E. coli* in high concentrations.

RAIN GARDEN DESIGN & EVALUATION

One product resulting from recently completed Wisconsin WRI research is a user-friendly computer model that can be used in the design and evaluation of rain gardens and bioretention

facilities. This model is now recommended by the Wisconsin Department of Resources (DNR) for use in meeting its new stormwater infiltration regulations and is available free of charge on the DNR website. A manual based on related WRI-funded research, Design Guidelines for Stormwater Bioretention Facilities, has been accepted for publication next spring by the University of Wisconsin Aquatic Sciences Center.

METHYLMERCURY FORMED IN GROUNDWATER

A WRI study conducted at the Allequash Creek watershed in northern Wisconsin determined that anoxic zones in shallow groundwater are an important site of methylmercury formation. This information will advance our understanding of mercury transport and methylation in groundwater and watershed response to mitigation of mercury inputs.

ESTROGENIC ENDOCRINE DISRUPTORS IN GROUNDWATER

A WRI-funded analysis of multiple groundwater samples from high capacity wells at five Wisconsin municipalities showed no estrogenic endocrine disruptor activity, leading the investigators to conclude that no infiltration of these contaminants from surface water into nearby groundwater is occurring. Also, analysis of multiple samples of septic influent, effluents, monitoring wells and soil water indicate septic systems using the biomicrobic aerobic and sand filtration system provided cleaner effluent than mound systems.

